

kizamu

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What is Kizamu?

- A computer-based sculpting system for creating digital characters
- Incorporates
 - New algorithms
 - Technical advances
 - Novel interaction paradigms
- Focus
 - High-end digital character design for the entertainment industry

Requirements for Digital Character Design

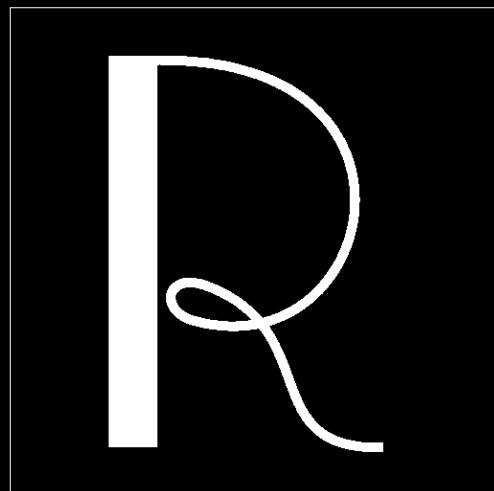
- Digital clay
 - Clay-like: intuitive to sculpt, represents both fine detail and organic shapes
 - Digital: can undo, script, duplicate, store permanently, etc.
- Responsive
 - Interactive on standard hardware
- Fits into the animation production pipeline
 - Accept scanned data as well as other standard representations
 - Produce standard representations as output

Kizamu System

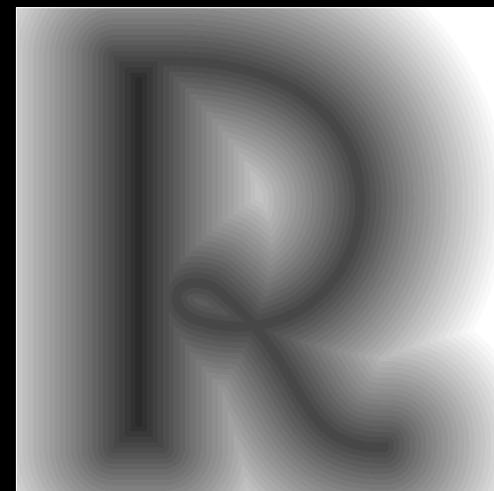
- Objects represented as Adaptively Sampled Distance Fields (ADFs)
 - ADFs can be directly and intuitively edited
 - ADFs represent fine detail and smooth organic surfaces
 - ADFs support fast processing with a reasonable memory footprint
- Volumetric sculpting interface that exploits the distance field to provide intuitive interaction
- Accepts range data, triangle models, Bezier patches, and implicit functions as input
- Produces LOD triangle models as output

A Brief Overview of ADFs

- Distance fields
 - A distance field is a scalar field that specifies the distance to the surface of a shape
 - The distance may be signed to distinguish between the inside and outside of the shape

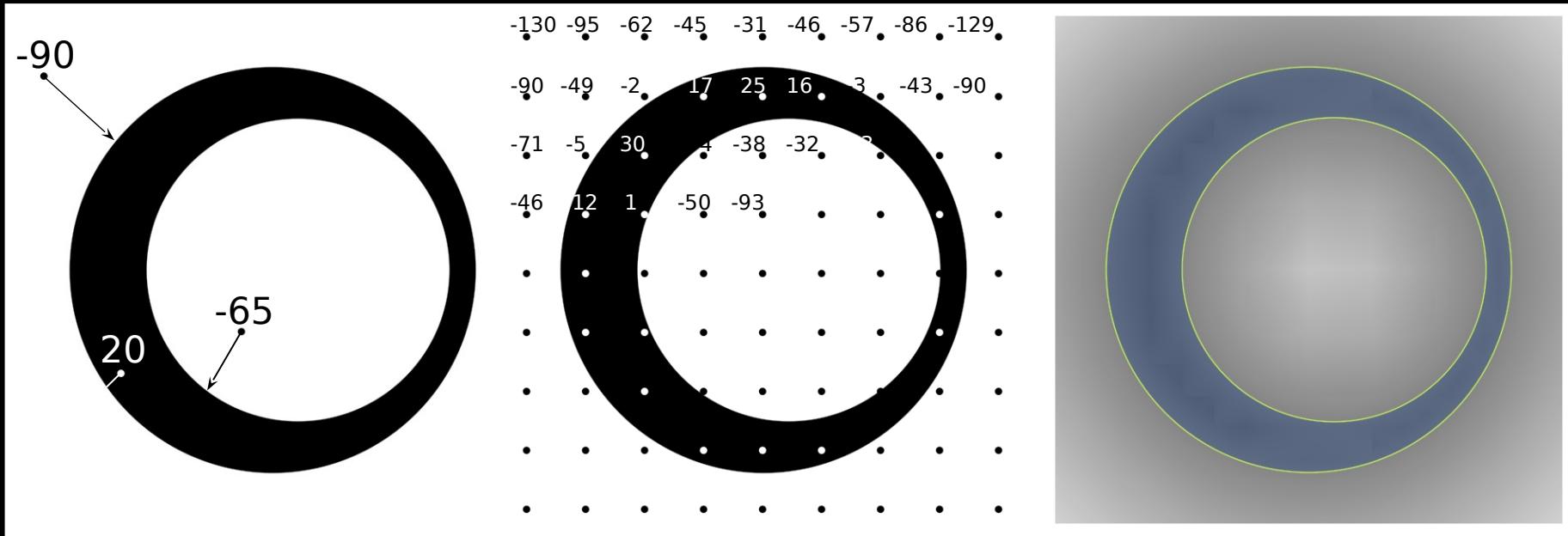


R shape



Distance field of R

Sampled Distance Fields



2D shape with
sampled distances
to the surface

Regularly sampled
distance values

2D distance field

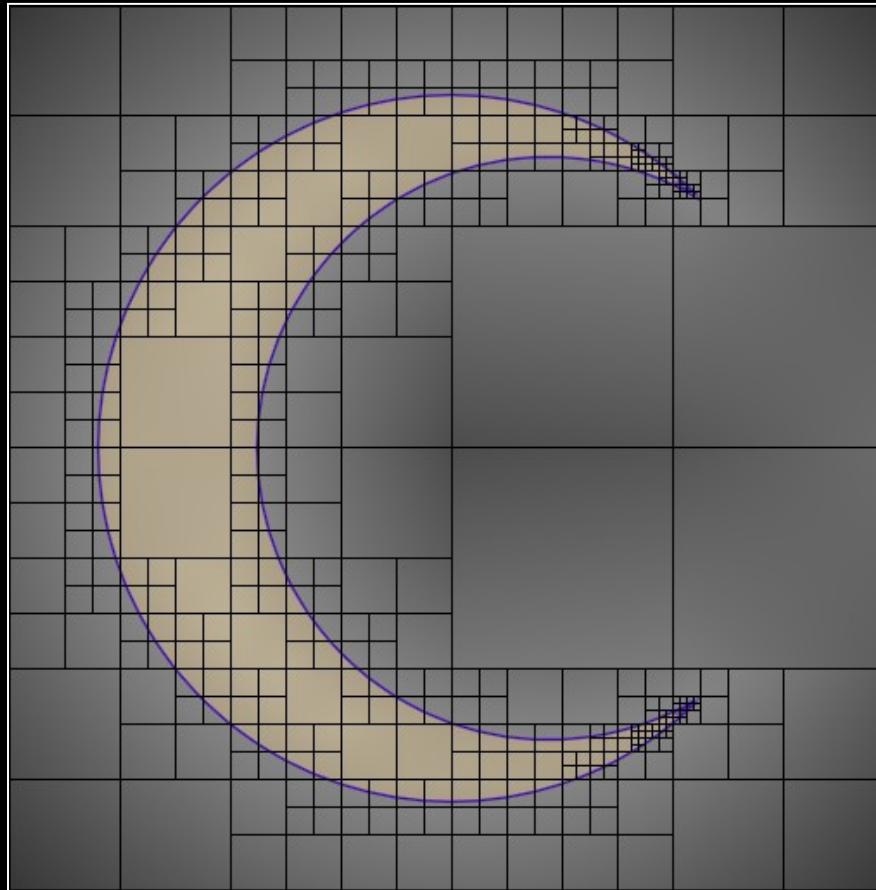
Regularly Sampled Distance Fields

- Distance fields must be sampled at high enough rates to avoid aliasing (jagged edges)
- Very dense sampling is required when fine detail is present
- Regularly sampled distance fields require excessive memory when *any* fine detail is present

Adaptively Sampled Distance Fields (ADFs)

- Detail-directed sampling of a distance field
 - High sampling rates only where needed
- Spatial data structure (e.g., an octree)
 - Fast localization for efficient processing
- Reconstruction method (e.g., trilinear interpolation)
 - For reconstructing the distance field and gradient from sampled distance values

Adaptively Sampled Distance Fields



A 2D crescent ADF and its
quadtree data structure

Advantages of ADFs for Editing

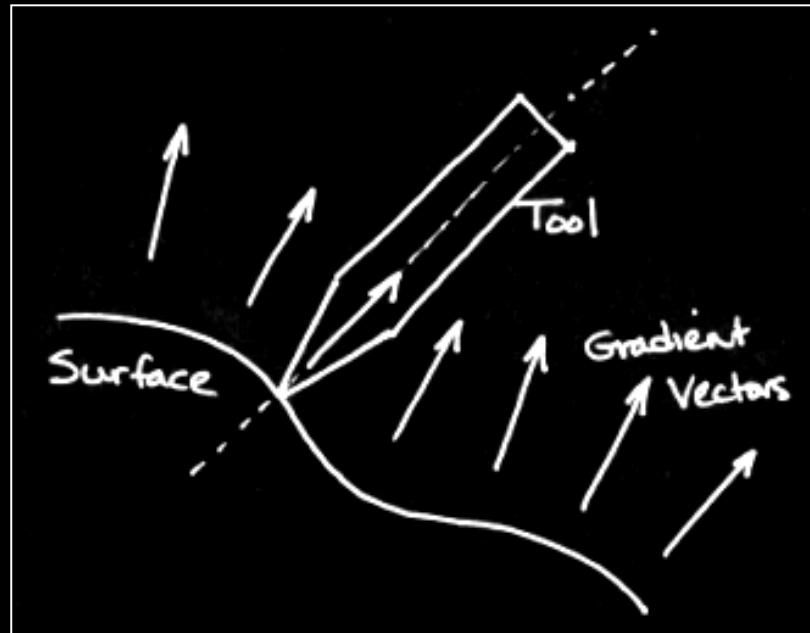
- Represent both smooth surfaces and sharp corners without excessive memory
- Sculpting is direct, intuitive, and fast using simple Boolean operations
- Does not require control point manipulation or trimming
- The distance field can be used to enhance the user interface
 - Guide the position and orientation of the sculpting tool
 - Enable distance-based constraints for carving

What was Required to Build Kizamu

- Innovations in the sculpting interface
- Advances in ADF generation and ADF editing
- New approaches for ADF rendering
- Methods for generating ADFs directly from range data and converting ADFs to triangle models

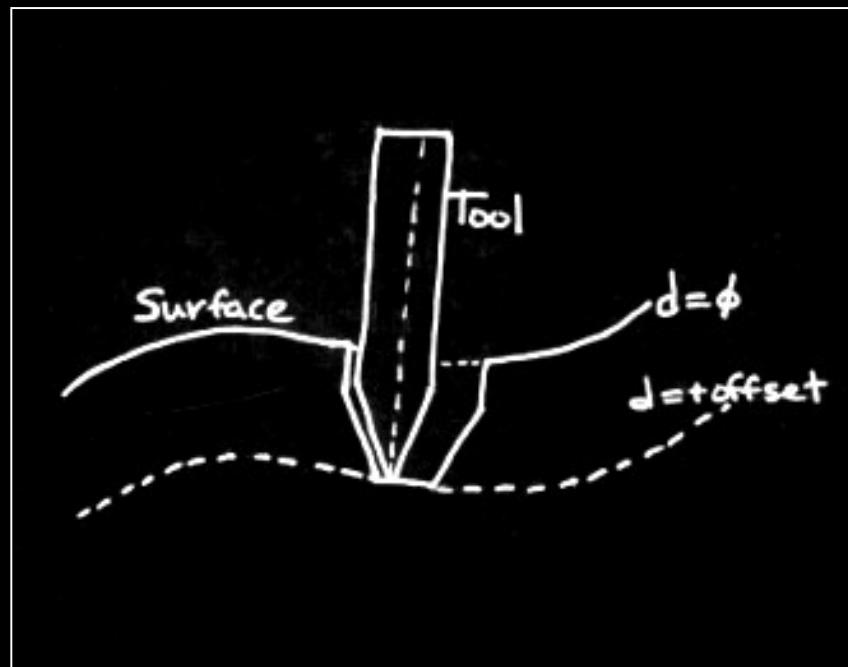
Sculpting Interface

- Surface following
- Distance-based constraints
- Control-point editing



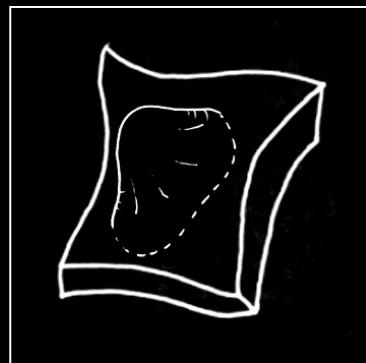
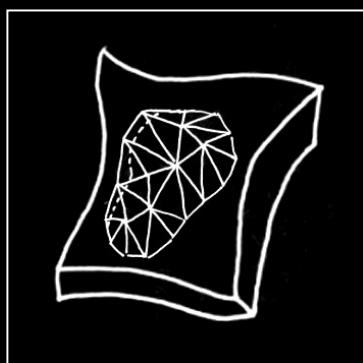
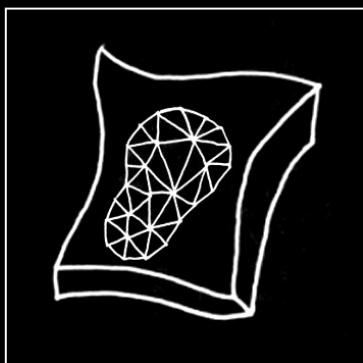
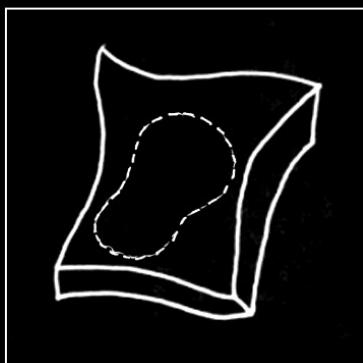
Sculpting Interface

- Surface following
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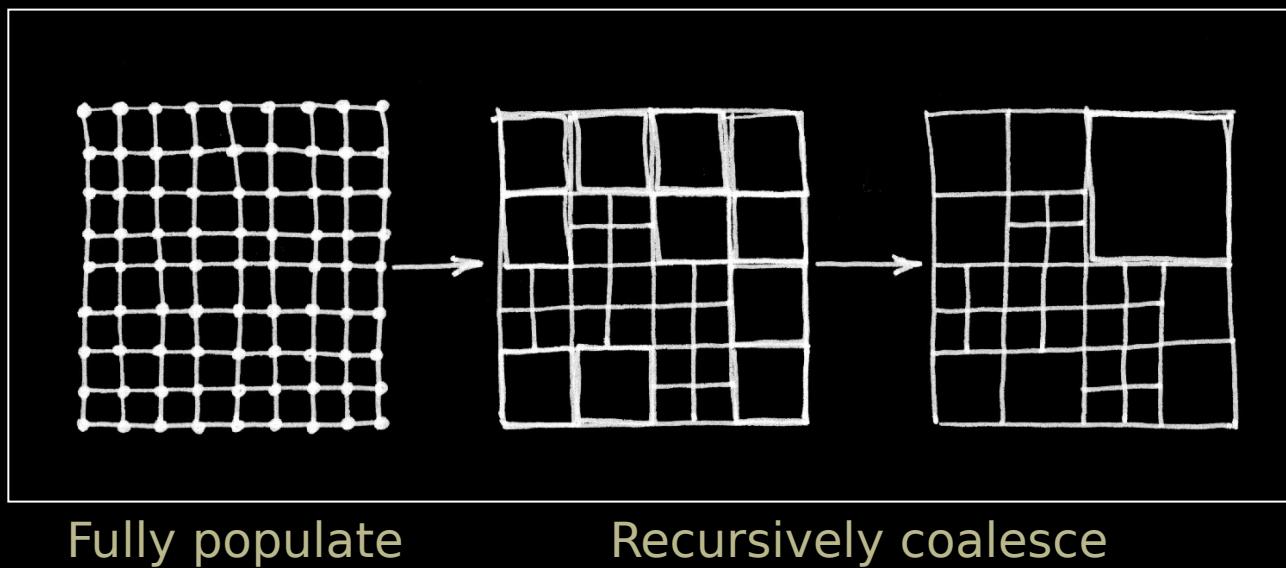
Sculpting Interface

- Surface following
- Distance-based constraints
- Control-point editing



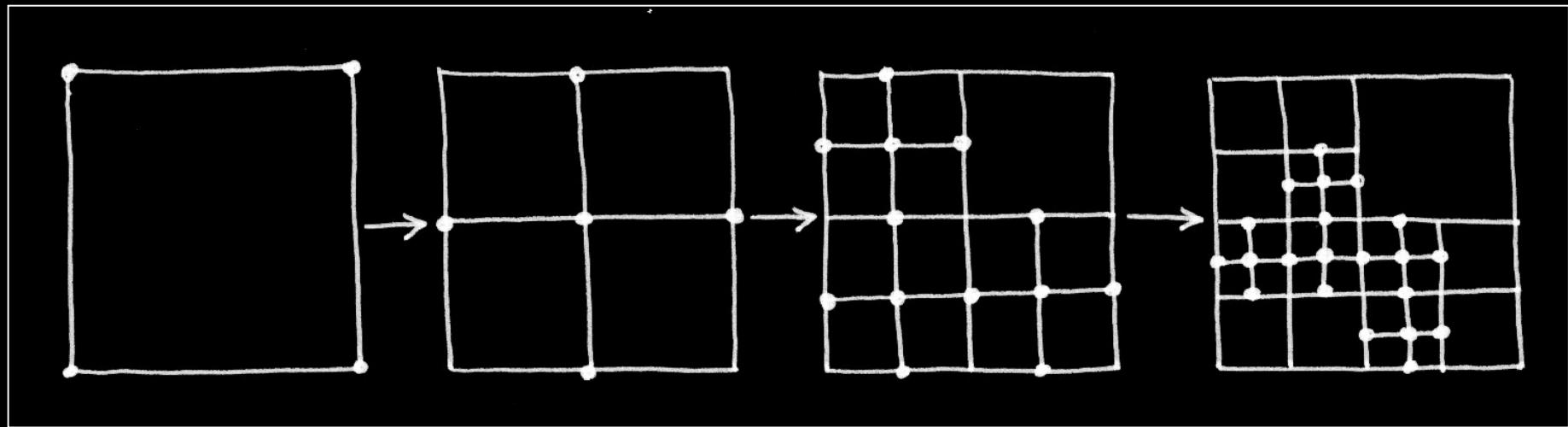
Bottom-up ADF Generation

- Requires too many distance computations, too much memory, pre-set resolution



Top-down ADF Generation

- Requires expensive neighbor searches and redundant distance computation



Initialize root cell

Recursively subdivide

Tiled Generation

- Reduced memory requirements, better memory coherency and reduced computation
- Significantly faster (20x)
 - 2 seconds vs 40 seconds for a level 9 ADF
 - 7.6 seconds for a level 12 ADF
- More detail ((8x)³ higher resolution)
 - level 12 and level 13 ADFs vs level 9 ADFs

Tiled Generation - Method Outline

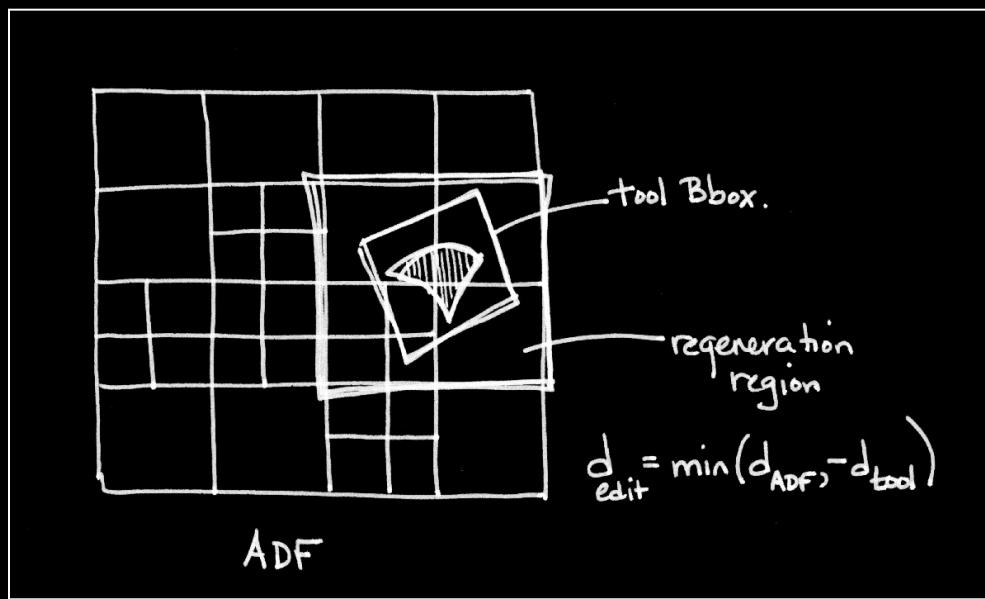
- Recursively subdivide root cell to a level L
- Cells at level L requiring further subdivision are appended to a list of candidate cells, *C-list*
- These candidate cells are recursively subdivided between levels L and $2L$, where new candidate cells are produced and appended to *C-list*
- Repeat layered production of candidate cells ($2L$ to $3L$, etc.) until *C-list* is empty

Tiled Generation - Tiling

- For each candidate cell, computed and reconstructed distances are produced *only* as needed during subdivision
- These distances are stored in a ***tile***, a regularly sampled volume
- Avoids recomputing distance values shared by neighboring cells. A corresponding volume of bit flags keeps track of valid distances in the tile.
- The tile resides in cache memory and its size determines L

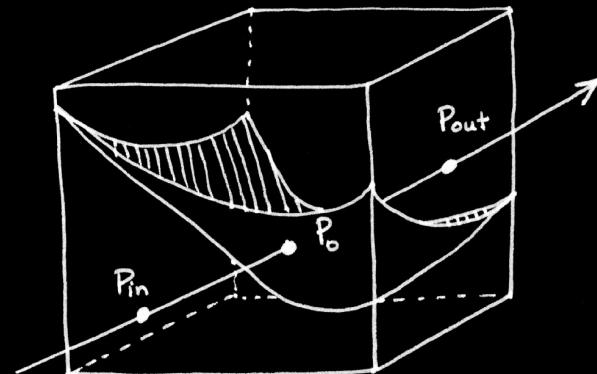
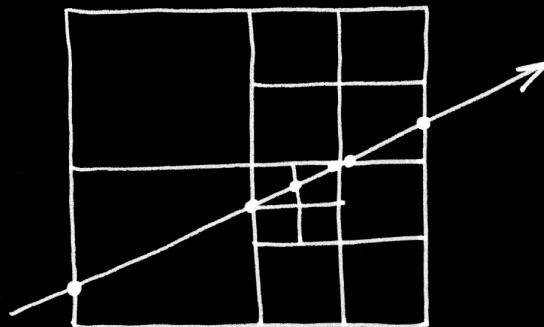
Sculpting

- Sculpting is localized regeneration
 - The ADF is regenerated inside cells that overlap the tool's bounding volume
 - Regeneration combines the distance fields of the ADF and the tool using CSG operations



Local Rendering

- Ray casting method

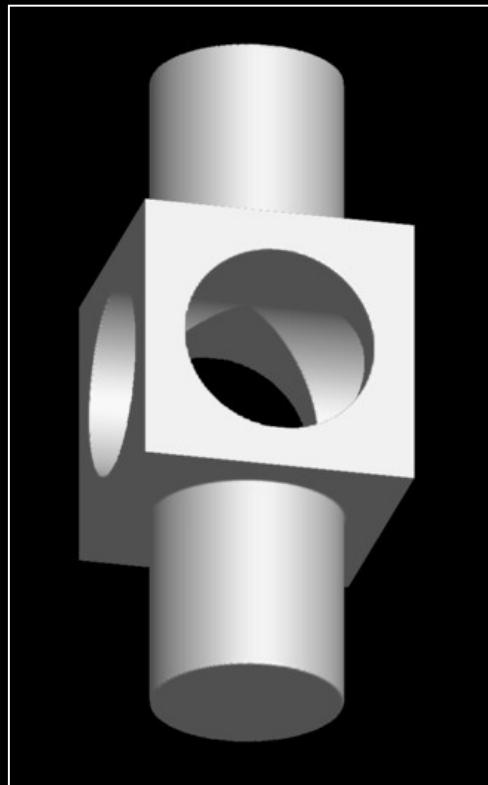


- Problems
 - Too slow for local updates on low-end systems
 - Woefully inadequate for global view changes

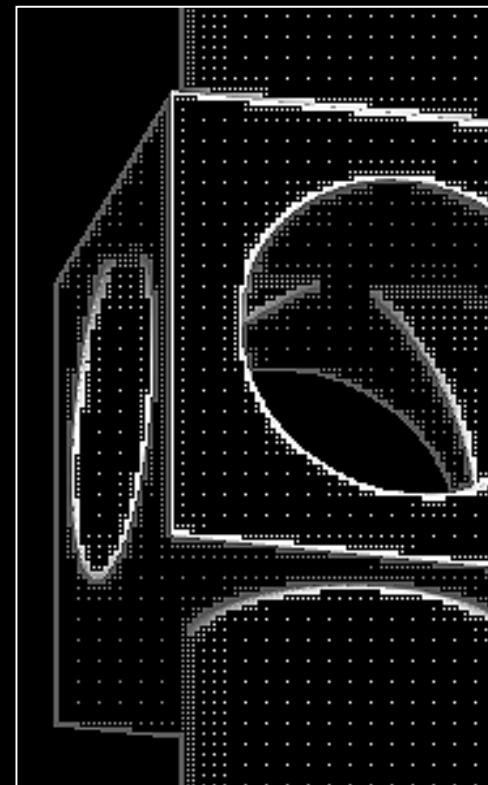
Adaptive Ray Casting

- Adaptive ray casting method
 - Image divided into a hierarchy of tiles
 - Tiles are subdivided according to perceptually based predicates
 - Pixels in tiles greater than 1x1 are bilinearly interpolated
- Achieve 6x speedup (10x for supersampling)

Adaptive Ray Casting



Adaptively ray cast ADF

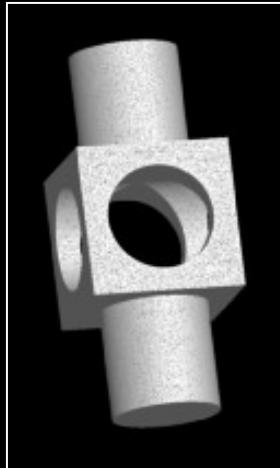


Rays cast to render part
of the left image

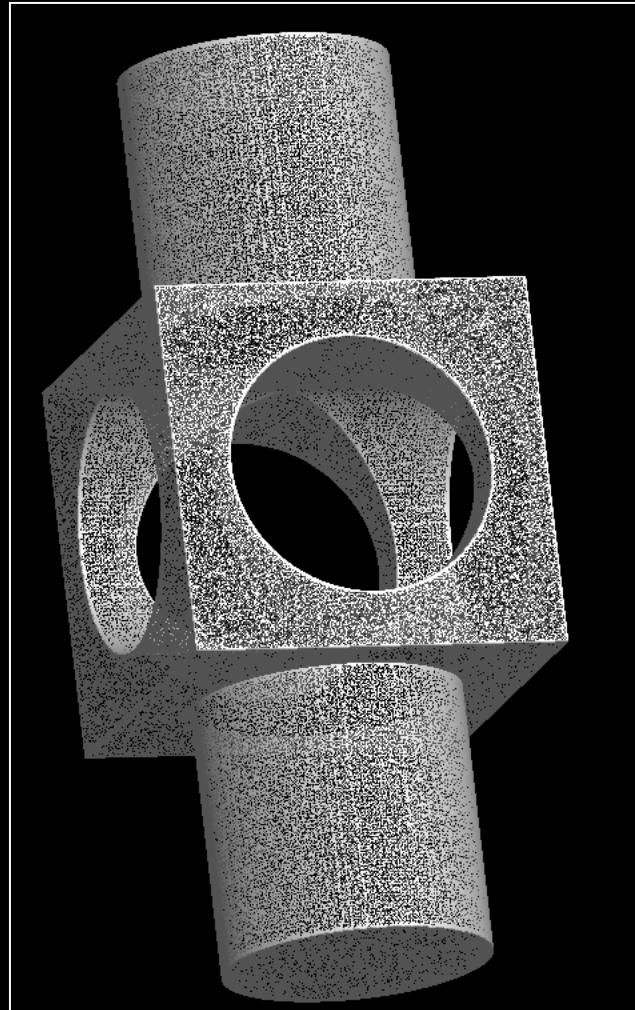
Global Rendering of Point Models

- Method for generating point models from ADFs
 - Seed each boundary leaf cell with randomly placed points, with number of points proportional to surface area within the cell
 - Relax the points onto the ADF surface using the distance field and its gradient
 - Optionally shade each point using the distance gradient
- Can generate 800,000 Phong illuminated points in 0.2 seconds
- Point models are sufficient for positioning

Point-based Rendering

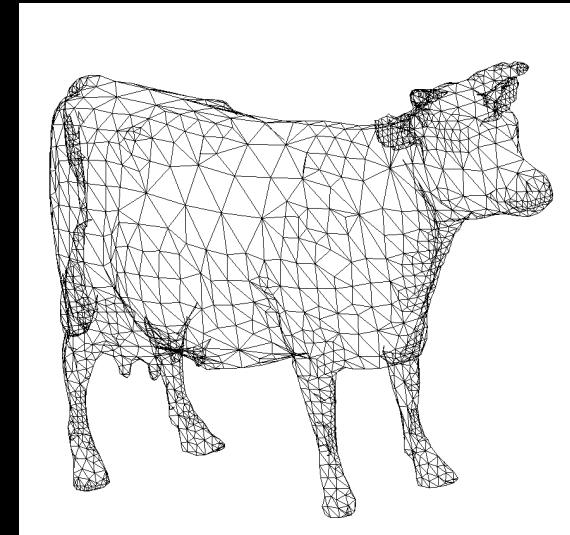


An ADF
rendered
as points
at two
different
scales



Global Rendering using Triangles

- Convert ADFs to triangle models and render interactively with hardware
- Fast new triangulation algorithm creates triangle models from ADFs on-the-fly
 - Watertight and oriented
 - Good-quality triangles
 - 200,000 triangles in 0.37 seconds
 - Can create LOD models

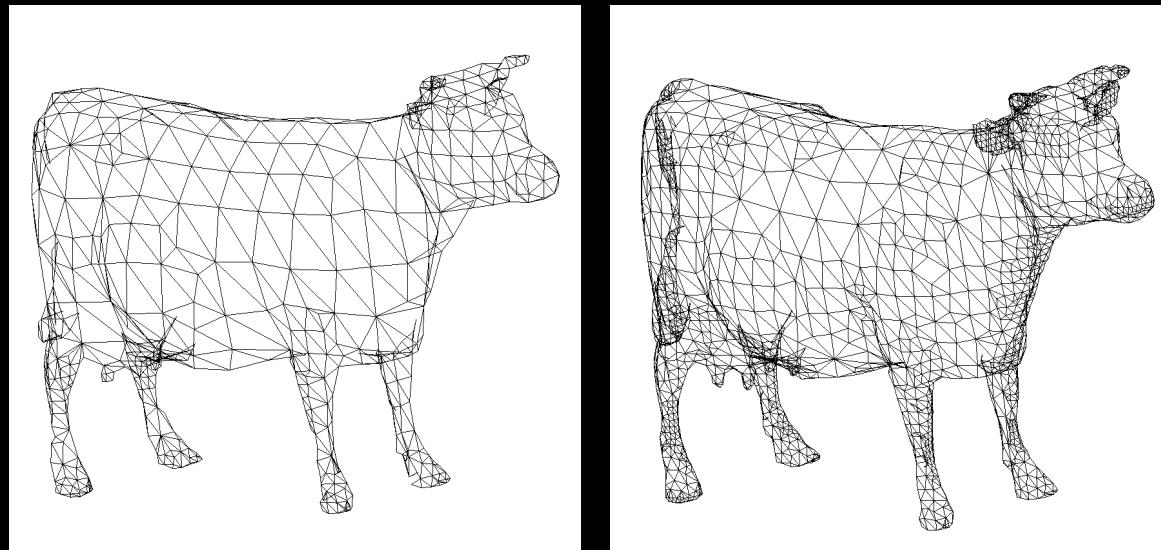


Converting to Triangle Models

- Seed
 - Assign a vertex to each boundary leaf cell of the ADF, initially placing vertices at cell centers
- Join
 - Join vertices of neighboring cells to form triangles
- Relax
 - Move vertices to the surface using the distance field
- Improve
 - Move vertices over the surface towards their average neighbors' position to improve triangle quality

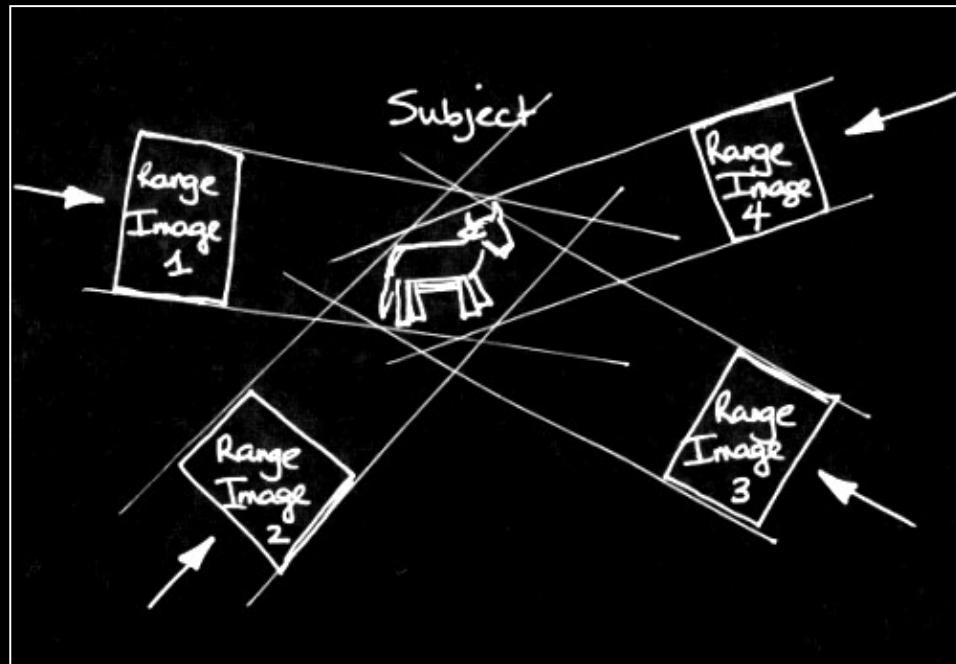
Creating LOD Triangle Models

- Adapt triangulation to generate LOD models
 - Traverse octree from root to leaf cells
 - Seed vertices in (possibly) non-leaf boundary cells that satisfy a minimum error criterion
 - Ignore cells below these in the hierarchy



Converting Range Data to ADFs

- Capture 2D range images from multiple views



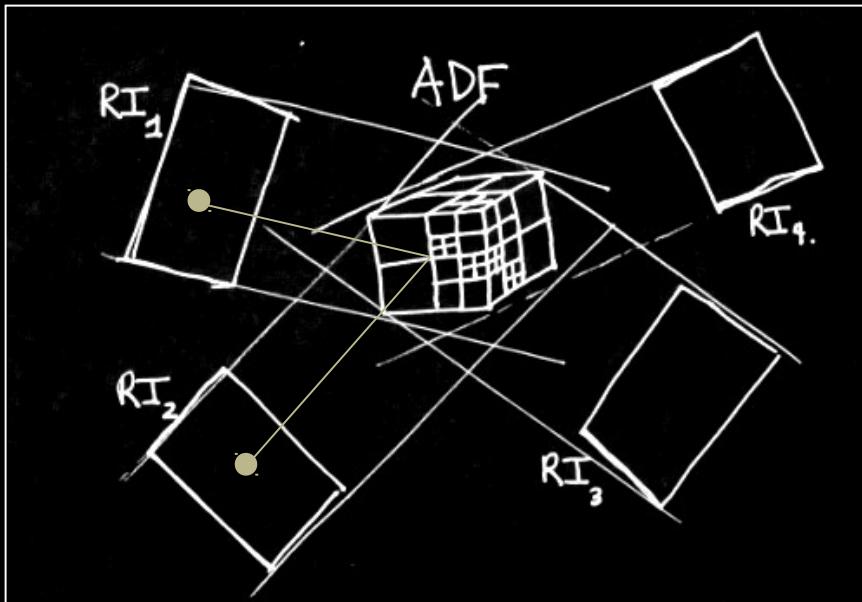
Range images collected
from several view points



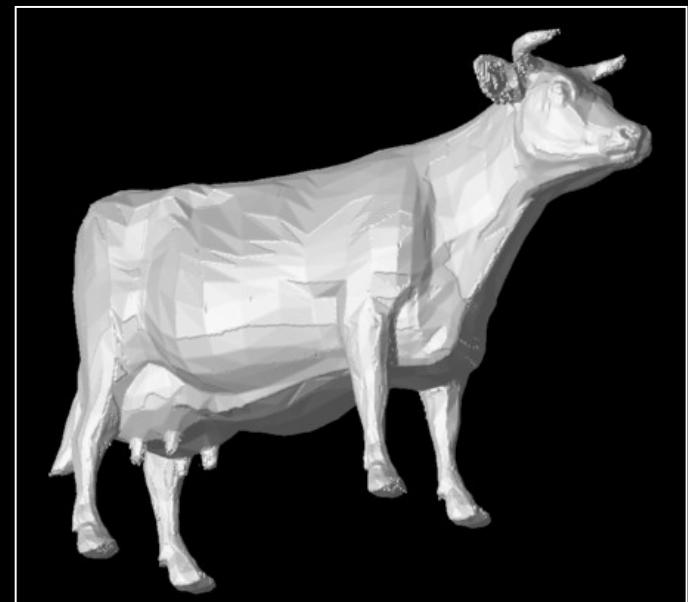
A range image

Converting Range Data to ADFs

- Combine distances from multiple range images to estimate ADF distance values

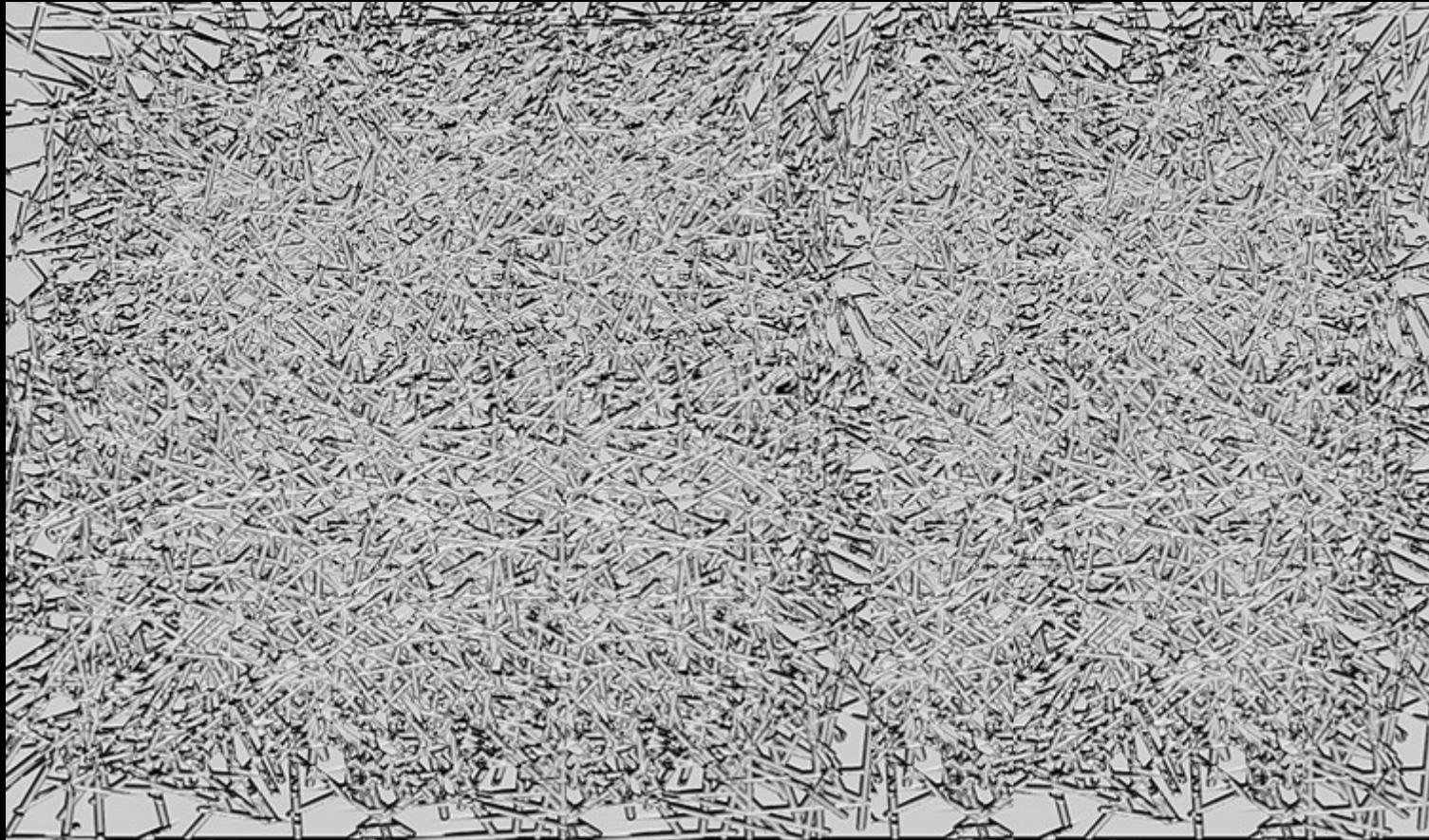


Combine distances from
multiple range images



ADF generated from 14
synthetic range images

Results – Detail



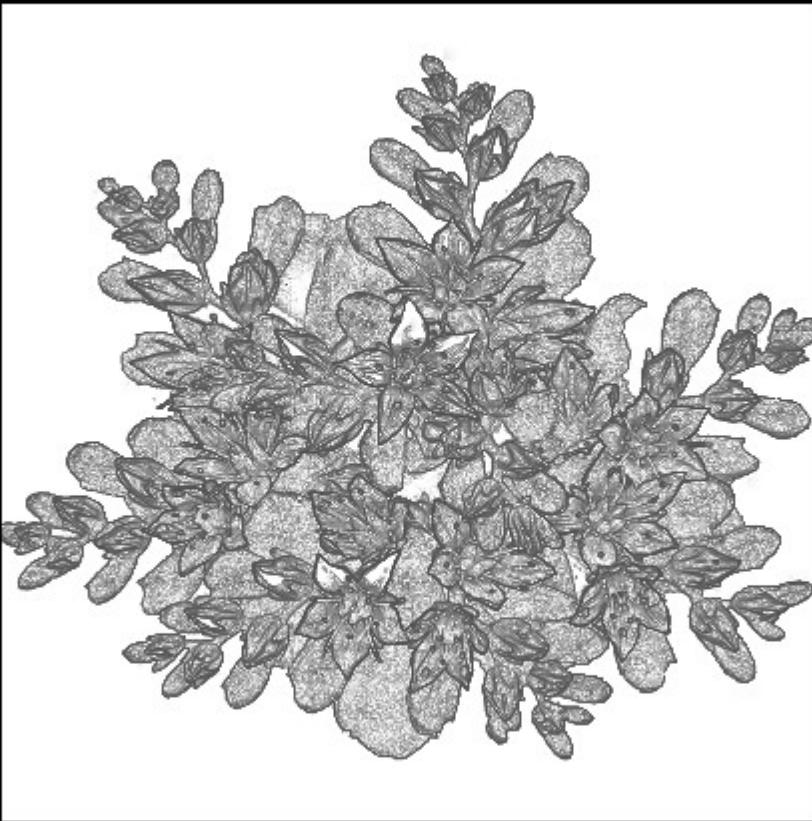
“Boston road map” sculpted with 2000
random chisel strokes

Results – Detail



ADF cow procedurally sculpted with 21,063 chisel strokes

Results – And More Detail



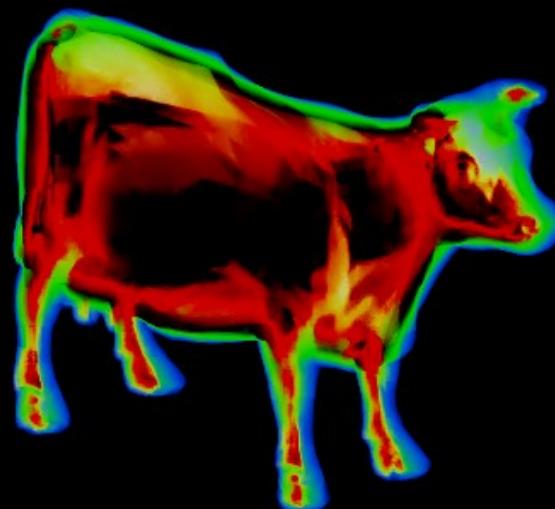
Flowers carved from a photograph using conversion from range images to ADFs



Kizamu Demonstration

New Directions

- ADFs provide a single representation for both surface and volume models
- Extend Kizamu to support the creation of detailed volumetric digital characters



With Thanks

- Joe Letteri
- John Arnold
- Ray Jones
- Jackson Pope